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Standardised method of spotlight surveys for crocodiles in the tidal rivers of the Northern Territory, Australia

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Abstract

Standardised spotlight survey procedures have been an integral part of long-term (1975-2012) monitoring programs for Saltwater Crocodiles *Crocodylus porosus* and Freshwater Crocodiles *C. johnstoni* in tidal rivers of the Northern Territory (NT) of Australia. These programs, implemented four years after depleted Saltwater Crocodile populations were protected from hunting in 1971, have been instrumental in documenting post-protection population recovery and evaluating management interventions. This article describes a standardised method for spotlight survey of crocodiles in tidal rivers, with particular emphasis on practical aspects that were not previously documented. It also shows example survey data and how it is analysed. This practical guide is primarily oriented at maintaining survey standardisation within the NT, but it should help wildlife managers to use standardised spotlight counting as a monitoring tool for crocodilian species in similar habitats elsewhere.

Introduction

The Northern Territory (NT) of Australia has a long history of monitoring its crocodile populations (Messel *et al.* 1981; Webb *et al.* 2000; Fukuda *et al.* 2011). The University of Sydney, in collaboration with the NT Government, initiated the first surveys in 1971 and implemented a standardised spotlight surveying program in tidal rivers in 1975 (Messel *et al.* 1981). Retaining this standardised methodology within the monitoring program has contributed significantly to the confidence with which survey results can be used to assess management interventions and anticipate future changes in the population (Webb *et al.* 2000; Leach *et al.* 2009; Fukuda *et al.* 2011).

Two species of crocodile occur in the coastal wetlands of the NT, the Saltwater Crocodile *Crocodylus porosus* and the endemic Australian Freshwater Crocodile *C. johnstoni*. Both were depleted historically due to uncontrolled hunting for skins. Saltwater crocodiles were hunted for 26 years (1945–71) before being protected (Webb *et al.* 1984) and were critically depleted by 1971, whereas Australian Freshwater Crocodiles were hunted intensively for only five years (1959–64) before protection. Saltwater crocodiles were historically abundant in tidal rivers and other coastal floodplain wetlands, whereas the majority of the Australian Freshwater Crocodile population was upstream in non-tidal rivers and billabongs.

Survey programs started in 1971, using a variety of methods (spotlight counts, aerial counts, track surveys, boat sightings) to locate remnant Saltwater Crocodile populations. Standardised spotlight surveys commenced in 1975 to monitor population trends as the recovery started (Messel *et al.* 1981; Webb *et al.* 1984; Webb *et al.* 2000). The subsequent recovery in abundance and biomass has been well documented (Webb *et al.* 1984; Fukuda *et al.* 2011) and the wild population now supports sustainable harvest programs (Webb & Manolis 1993; Leach *et al.* 2009). This has only been possible because the long-term monitoring program, with standardised survey methods, has provided unequivocal evidence of the changing status of Saltwater Crocodiles over time and the effects of management interventions. Although Australian Freshwater Crocodiles were not the primary target of the monitoring programs within tidal rivers, it soon became apparent that they too were found in this habitat. Spotlight surveys could therefore provide indices of temporal change in abundance, population size structure and distribution of this species.

The survey method applied in the NT from 1975 onward was originally described by Messel *et al.* (1981) and extended by Bayliss (1987). Since then, some components have been adjusted to take advantage of new technologies. The current NT survey program includes a suite of practical considerations, learned through experience, that have not previously been documented despite their obvious value for those undertaking surveys.

The central aim of this paper is to provide a concise, updated and practical guide for standardised spotlight surveying of crocodiles in NT tidal rivers, based on 37 years of experience. If this method is applied to populations of Saltwater Crocodiles or other crocodilian species in similar habitats elsewhere, it should enable their changing status to be monitored prospectively. Recovery of diminished populations could be compared directly with recovery of Saltwater Crocodiles in the NT (Fukuda *et al.* 2011). The survey method is also applicable to non-tidal rivers, billabongs and lakes with an open water surface, although each habitat type may have different visibility biases.

Survey Methods

Environmental context

As described by Messel *et al.* (1981), the tidal rivers of the NT fall into a number of different categories depending, in part, on whether they meander across floodplains or are drowned river valleys. All contain saline water at the mouth, but during the annual dry season (April/May to November) a salt wedge moves progressively upstream. Depending on the volume of freshwater flowing into the upper reaches the dry season salinity profile may decrease with distance upstream, or increase due to evaporation if the input of freshwater is limited. The tidal sections of NT rivers are typically lined with mangroves and floodplain grasses and sedges. Most tidal rivers in the NT have two tidal cycles per day with an average of approximately 5 m between the heights of high and low tides. Annual average rainfall is around 1400 mm, but 95% of this falls within a discrete wet season (November to April/May). Increased water flow during the wet season restricts upstream progression of tidal influence in most rivers. During the dry season, water inundates the mangroves on high tides and exposes mud banks with limited vegetation at low tide. The dry season, in which little rain falls, can be broadly subdivided into a cool period (May to August), during which crocodiles bask, and a hot period (September to November) when they avoid heat, reducing the chance of them being seen.

Initial survey

When surveying a river for the first time, a preliminary survey at low tide during the day should be conducted to check river conditions, such as access to a boat ramp, location of barriers (rocks, sand bars and logs), water depth and travelling time to the starting point of survey, so that the nocturnal spotlight survey can be done safely. If long-term monitoring is planned, results of this preliminary survey will help design the survey strategy for that river. Given that crocodile densities vary within and between rivers (Fukuda *et al.* 2007; Fukuda *et al.* 2011), separate survey sections, with different start and finish points, may not be equivalent in terms of distance or crocodile abundance. For example, surveying the same distance in different rivers may require different amounts of time and effort. Each survey section should be reasonably expected to be surveyed in one night (see below).

Survey planning

The start and end points of each section must be exactly the same between years, because crocodile abundance and distribution along a river varies over time and space (Fukuda *et al.* 2007; Y. Fukuda, unpubl.),. In addition, the effect of seasonal changes in temperature and water level that affect crocodile behaviour (Webb 1991) must be minimised. Hence repeated surveys over years should be conducted in the same month, ideally within the same two-week period. The exact date and time of a survey will depend on the tide. Surveys are conducted during a low tide at night, usually in mid to late dry season (winter). In the coldest period of the dry season, when water temperatures are higher than air temperatures, most crocodiles are in the water at night where they can be spotted at low tide (Hutton & Woolhouse 1989; Webb 1991). During warmer periods of the dry season, a higher proportion of crocodiles remains on the bank amongst vegetation or buried in mud, sites where there are lower probabilities of sighting them. Superimposed on this variation is movement of crocodiles from temporary water bodies (e.g. floodplains and billabongs) into the river mainstream as the dry season progresses. This is in part moderated by the extent and timing of the previous wet season rains (Webb 1991), which affect water levels in these temporary water bodies. Detection probabilities in riverine situations also increase with decreasing water depth (Fujisaki *et al.* 2011).

Surveys should proceed from downstream (the river mouth) to upstream (inland), with the survey boat staying ahead of the incoming tide. This maximises the duration of water levels around low tide suitable for conducting surveys. Hence daily tide tables and the timing of tidal delays up rivers need to be assessed carefully. Maximum exposure of bare river banks without vegetation which shields crocodile eyes from the spotlight occurs at low tide. Spring tides are preferable to neap tides because they expose more of the bank for longer periods. Around 1–2 hours on either side of low tide is normally suitable for surveying at any one site, so surveys should start at the downstream limit of the section on a falling tide, around 2 hours before low tide.

The maximum survey time and distance covered (moving upstream) will largely be determined by crocodile density and speed of survey. In tidal rivers with medium to high densities of crocodiles (>5 eye-shines detected per kilometre), average speed of progress along a river is between 8 and 10 km/h, allowing 40 km to be surveyed in 4-6 hours. Spring low tide progresses upstream at approximately 20 km/h in the tidal portion of many rivers in the NT. Thus, by commencing 2 hours before the time of low tide, the low tide will reach the boat's position slightly after the halfway point is reached. Surveys should only start earlier than 2 hours before low tide at the start point if the water level is already well below the level of the fringing vegetation. Likewise, if the incoming tide raises the water level to cover exposed mud banks earlier than expected, surveys should cease. A long river (>50 km) may need to be subdivided into defined sections that can be surveyed on consecutive nights.

If the river width exceeds about 400 m, each side should be surveyed separately (e.g. midstream-west bank and midstream-east bank). Tributaries (side creeks) should be surveyed separately from the mainstream; additional time should be allocated to allow for time needed to travel in and out of each tributary. Survey sections in the same river, particularly adjacent sections, should ideally be surveyed on consecutive nights, to reduce the possibility of crocodiles moving between sections. All the sections should be surveyed in the same direction (from downstream to upstream).

A detailed schedule, along with a large-scaled map of each section such as those prepared by Messel *et al.* (1982) for the tidal rivers in the NT, and a projected survey timetable, should be developed for each river. For longer rivers with multiple survey segments, one or more extra nights should be scheduled to allow unexpected delays. Access to a boat ramp, travelling distance, and time to the start and end point of survey section should be included in the schedule. A typical spotlight survey requires a minimum of three people (boat driver, spotter and data recorder) as described below. A full checklist of equipment required for a spotlight survey (Table 1) will help ensure that surveys do not need to be abandoned because some critical element was forgotten.

Safety procedures

Physical conditions during a survey can be difficult. A survey, including travelling to the start point, typically takes 8-12 hours. Personnel may be exposed to very hot conditions on the water during the day and cold conditions (including wind chill) at night, which means appropriate protective clothing is essential. The spotlight may attract large amount of insects, and mangroves often contain mosquitoes and biting midges ('sandflies'). In some situations protective glasses may be needed, and use of effective insect repellent improves comfort and reduces the risk of acquiring insect-borne disease. A break of 10 minutes every 90 minutes is good practice as it allows the team members to retain concentration during a survey. Sufficient food and water should be taken on each trip (see Table 1 for quantities).

To be prepared for emergencies, a first aid kit, satellite phone, emergency flare, distress radio beacon (e.g. marine Emergency Position Indicating Radio Beacon (EPIRB)), life jackets and repair tool kit must be present on all survey boats. All team members should be trained in first aid. Although direct contact with crocodiles during a spotlight survey is highly unlikely, one team member with an appropriate qualification should carry a compact firearm. The boat should be equipped with oars, ropes, spare propeller and sufficient fuel. Oars are important for escaping from shallow water where the engine cannot be used. Development of a safety protocol specifically formulated for a spotlight survey, including a communication plan (e.g. contacts for emergency), is highly recommended.

Boats and boat driving

A survey boat needs to be large enough to accommodate at least three people and the survey gear, but also small enough to operate at low tide in shallow and/or narrow streams. A 4.5 m aluminium dinghy with a 30 horse power (hp) engine should be used

Table 1. List of survey equipment typically required for three people for one run of a spotlight survey (survey distance <50 km).

Item	Quantity
Batteries (D, C, AA, AAA)	12 each
Battery (12 V, 100 A)	1
Emergency flare	1
EPIRB	1
Fire arm	1
First aid kit	1
Food and water	9 snacks and 9 L
Fuel	25 L
Gloves	4 pairs
Goggles	4
Hand held GPS	1
Head lights	4
Insect repellent	3
Life jackets	4
Light globes	3
Maps	3
Note books and pens	2 each
Oars	2
Paper data sheets	10
PDA cables and cases	3 each
PDAs	3
Propellers	3
Protective clothes	3
Rain coats	3
Repair tool kit	1
Ropes	3
Satellite phone	1
Spotlights (100 W)	2
Sun screen	1
Waterproof torch	1

for most crocodile surveys (Figure 1), although 5-6 m boats powered by 50-60 hp engines can be used in large rivers. The boat should be equipped with adequate fuel and carry all necessary safety equipment (see Table 1). The boat driver should have adequate experience and may be required by government regulation to hold an appropriate qualification (e.g. Coxswain certificate). Boat drivers should be familiar with techniques used in crocodile spotlight surveys as described below.

Travelling speed during a survey largely depends on the condition of the river (water depth, crocodile density, visibility through vegetation, etc), but 15-25 km/h appears ideal for most tidal rivers in the NT. A hand-held spotlight (Figure 2) is used to detect eye-shine. Given the time taken to approach and record crocodiles sighted, surveys should proceed at 8 to 10 km/h if there is a medium to high density of crocodiles (>5 eye-shines per kilometre). Total distance travelled during a survey, taking into account the approaches to crocodiles, is around 1.5 to 2.5 times the linear river length. The boat should not go faster than 30 km/h even in a very low density site, because eye-shine is noticeably more difficult to detect at higher speed. The boat should slow down as each crocodile is spotted and approach the animal as closely as possible for species identification and size estimation. Boat speed should be reduced gradually to minimise any bow wave or sudden change in engine noise likely to increase the probability of the crocodile fleeing and submerging. We recommend an approach speed of 5-10 km/h within 50 m of a crocodile. The boat should stay on the midstream line of a river when searching for eye-shine (Figure 3). If an eye-shine is spotted on a bank, the boat should slow down and approach the crocodile at right angles to the edge of the water. The boat should return to the midstream for the next eye-shine (Figure 3). Even if multiple eye-shines are recognised along one bank in relatively close proximity (e.g. 50 m), the boat should not remain close to the bank in moving from one crocodile to the next, because crocodiles are less likely to move off if approached at a right angle from the midstream line. The wave from a boat approaching slowly parallel to the bank is more likely to disturb animals in the most common location, at the edge in shallow water. The boat driver needs to pay constant attention to signals from the spotter (Figures 4–8) as well as to the environment (e.g. water depth, currents, logs and trees in the water).

Spotlighting crocodiles

Crocodiles are spotted using a hand-held spotlight (Figure 2), of at least 100W (200 000 candlepower), powered by a lead-acid battery (12 V, 100 Ah). For narrow creeks and billabongs, light intensity may need to be lowered for better spotting crocodiles. The spotter stands at the bow of the boat with the spotlight held near eye level. Spotters should scan the water surface, water edges, banks and vegetation with the light, in a zigzag manner from one side of the river to the other, of searching for the eye-shine of a crocodile. An eye-shine of a crocodile glows pink, red or orange in the light (Figure 9) and is often visible from a long distance (more than 300 m) in clear conditions. Since visibility of eye-shine is greatly reduced in smoke, fog, mist or rain, surveys should not be carried out in these conditions. Other animals such as Barramundi (*Lates calcarifer*), Water Buffaloes (*Bubalus bubalis*), feral Cats (*Felis catus*) and wallabies also refleet eye-shine in the spotlight, but these animals can be easily distinguished from a erocodile with some experience, because they have different eolours in the eye-shine. If spotters move the light too slowly, or fix the light on a crocodile in the distanee and cease searching the banks as it is approached, the probability of missing potentially visible erocodiles will increase.

Signals for effective communieation between the spotter and boat driver are important (Figures 7–11). The spotter is responsible not simply for locating croeodiles, but for directing the boat driver around obstacles that are not visible to the driver (e.g. submerged logs, roeks and sand bars), and for directing the approach to observed croeodiles.

When a erocodile eye-shine is recognised the boat should continue to move upstream, in midstream, while the spotter ensures no other eroeodiles are being missed on either side. The spotter then directs the boat towards the spotted crocodile, with the aim of a close approach to ascertain erocodile species and size. Approaching from midstream at near right angles to the crocodile maximises the chance of getting a elear view of the crocodile before it moves away. The spotlight beam should be direeted on or immediately above the eye-shine as the boat approaehes, beeause this seems to discourage the erocodile from moving off.

Figures 1–2. Equipment used for croeodile survey: **1.** Boat with a 30 hp engine; **2.** Spotlight (100 W) connected to a battery (12 V, 100 A);

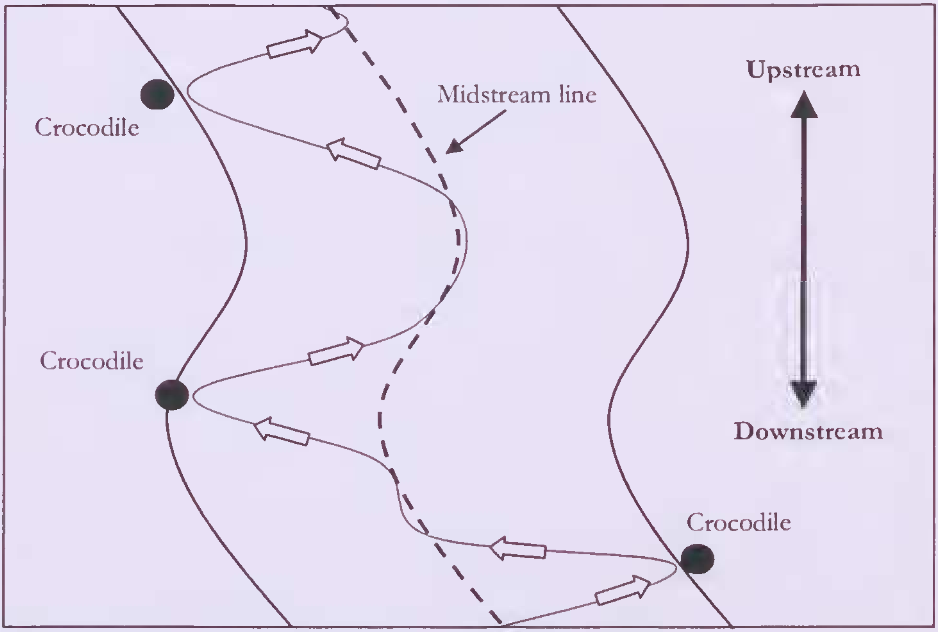
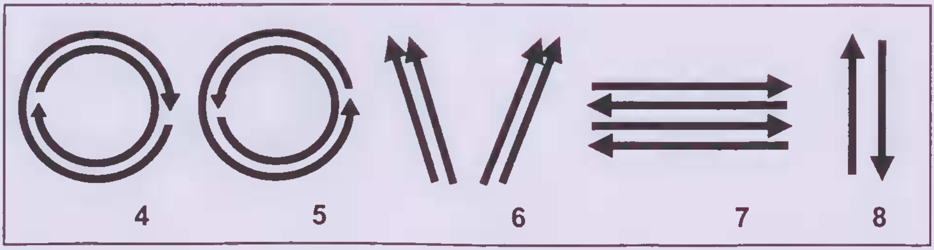


Figure 3. Track of survey boat during a nocturnal spotlight crocodile survey. Solid lines indicate river banks. The boat should move upstream and stay on the midstream line (large dashed line) and approach each crocodile from the midstream line. In a wide river, the boat should remain at least 10 m from the water's edge when running parallel to the bank.



Figures 4–8. Spotlight signals used to communicate to the boat driver during a spotlight survey of crocodiles: **4.** Clockwise circles indicate "go faster"; **5.** Anticlockwise circles indicate "go slower"; **6.** Up to the left/right indicates "go left/right"; **7.** From side to side indicates "stop the boat"; **8.** One flip up and down indicates "one crocodile in the direction of an eye-shine". All signals should be shown clearly in the front, high enough to be obvious to the driver.

Total length (TL) of a crocodile refers to the distance from the tip of the snout to the tip of the tail and is usually estimated using 0.3 m (=1 ft) intervals. Crocodile size usually ranges from 0.3 to 5.4 m (1 to 18 ft) for Saltwater Crocodiles and 0.3 to 3.6 m (1 to 12 ft) for Freshwater Crocodiles. Saltwater crocodiles smaller than 0.6 m (2 ft) and Freshwater Crocodiles smaller than 0.3 m (1 ft) are often recorded as "hatchlings of the year". In most cases only the crocodile's head and anterior neck are visible in the water, and spotters need to estimate size from this portion. In Freshwater Crocodiles, and in Saltwater Crocodiles between 1.2 and 4.2 m long, TL is around 7 times head length (HL) (Webb & Manolis 1989; Fukuda *et al.* 2013). The HL/TL ratio increases with body size and a 1:8 ratio should be used for large Saltwater Crocodiles (>4.2 m) (Fukuda *et al.* 2013). As a general guide, the head of large crocodiles can take on a very "bulky" appearance; the head of a 5 m crocodile appears to have twice the physical bulk of the head of a crocodile with a TL only 1 m shorter. The HL/TL ratio should be used only as a guide. Experienced spotters rely on their familiarity with the variable appearance of crocodiles of different sizes and estimate TL from head and neck size rather than mere HL. In general, spotters who are involved in capturing crocodiles make more accurate TL estimates.

Figure 9. Eye-shine of a saltwater crocodile in a spotlight. An eye-shine usually glows in bright red in the light and may be visible from a distance (approximately 300 m) in clear conditions.

Observer bias in the ability to detect eye-shine is generally small, but is higher for estimating TL, both within and between individual spotters (Choquenot & Webb 1987; Webb *et al.* 1989). It is essential that the spotlighter has sufficient training at estimating TL before they conduct surveys.

If a crocodile submerges before its size is estimated, it is recorded as "eyes only" and no estimate of TL is recorded. In some rivers, Freshwater Crocodiles and Saltwater Crocodiles co-inhabit at high densities. Accurate identification of species, particularly for small crocodiles, requires some experience. Freshwater crocodiles have narrower snouts with post-occipital scales behind the cranial platform and a lower proportion of the head is occupied by the cranium (although this is not evident in smaller animals). Saltwater crocodiles have raised wider cranial platforms and rarely have post-occipital scales behind the cranial platform (Richardson *et al.* 2002).

The position of crocodiles located within the river is recorded in one of six categories, defined by Messel *et al.* (1981): midstream (MS), shallow water on edge (SWOE), on mud (OM), in mud (IM), in vegetation (IV) and in vegetation in water (IVIW).

Data recording and navigation

The spotter's determination of species, TL and position (e.g. *C. porosus*, 6-7 ft, MS) is called out to the data recorder who sits adjacent to or behind the spotter in the boat. Although data can be recorded manually on paper (Figure 10), electronic data entry using a Personal Digital Assistant (PDA) or palmtop computers (Figure 11–13) has some technical advantages for efficiency. The PDA should contain a Global Positioning System (GPS) that records a complete track of the survey run and a data recording program that records the detail of each crocodile observed during the survey (Figure 14). Other than the continuous survey track, the GPS records the coordinates of the boat when it approaches each crocodile eye-shine as closely as possible. The data recording program should be able to accommodate all the elements of each observation (date, time, species, TL, position and GPS location). Such data recording programs can be developed with a desktop computer and installed on a PDA using software such as CyberTracker (CyberTracker Conservation 2012) or NS Basic (NS BASIC Corporation 2012). Paper datasheets should be available on the boat in case of technical failure of the PDA.

The data recorder is responsible for navigation using detailed topographic maps (1:50 000 and 1:100 000) in both paper and electronic form. They should be familiar with the survey area and any boat hazards it presents, and should record general information pertaining to each survey such as date, weather conditions, coordinates and time at the start and end points, and names and roles of the survey members.

Crocodile Spotlight Survey

Location: ______________________________

Date: ________________

Spotter: ________________

Recorder: ________________

Boat driver: ________________

Start point: ______________________________

Finish point: ______________________________

Start time: ________________

Finish time: ________________

Notes:

#	Species	Size	Position	GPS	Notes
1					
2					
	As many rows as practical				
25					

Figure 10. Front page of a paper datasheet previously used to record crocodile observation data. Electronic data recording on a PDA is now preferred and provides more efficient spatial data capture for GIS, but paper datasheets are available as backup (the full data sheet can be downloaded from Appendix A of the supplementary material).

11 12 13

Figures 11–13. Electronic data entry: **11.** Personal Digital Assistants (PDAs) for data recording and navigation; **12–13.** Two screenshots of PDA: **12.** Crocodile data recording screen; **13.** GPS mapping program.

Species	Size	Position	Date	Time	Latitude	Longitude
C. porosus	6-7	SOWE	06/07/11	19:23:23	-12.66718	131.3344
C. porosus	5-6	SOWE	06/07/11	19:24:18	-12.66893	131.3329
C. porosus	11-12	IV	06/07/11	19:25:59	-12.66872	131.3338
C. porosus	2-3	SOWE	06/07/11	19:27:38	-12.6706	131.3324
C. porosus	6-7	SOWE	06/07/11	19:27:52	-12.67099	131.3323
C. porosus	12-13	SOWE	06/07/11	19:28:38	-12.67234	131.3331
eyeshine	0	IV	06/07/11	19:29:16	-12.67235	131.3331
C. porosus	11-12	SOWE	06/07/11	19:30:08	-12.67326	131.3331
eyeshine	0	IV	06/07/11	19:30:35	-12.67399	131.3331
C. porosus	8-9	SOWE	06/07/11	19:31:05	-12.67471	131.3321
C. porosus	13-14	IV	06/07/11	19:32:24	-12.67506	131.3329
eyeshine	0	MS	06/07/11	19:32:48	-12.67548	131.3328
C. porosus	12-13	SOWE	06/07/11	19:33:35	-12.67668	131.3335
eyeshine	0	SOWE	06/07/11	19:34:22	-12.67789	131.3345
C. porosus	12-13	SOWE	06/07/11	19:34:42	-12.67833	131.3347
C. porosus	4-5	SOWE	06/07/11	19:36:39	-12.68222	131.3345
eyeshine	0	IV	06/07/11	19:36:57	-12.68196	131.3345
eyeshine	0	MS	06/07/11	19:37:50	-12.68305	131.3332

Figure 14. Raw data output of crocodile sighting data extracted from a data recording program (e.g. CyberTracker or NS Basic) in a PDA. These data can be presented on a map (Figure 16) or used to calculate the density and population structure of crocodiles (Tables 2–3).

For navigating the boat, Geographic Information System (GIS) or navigating programs for a PDA such as ArcPad (esri 2012) or OziExplorer (Des & Lorraine Newman 2012) are useful because they have functions to show the real-time location of the observer and record the track of a survey run. The use of two PDAs in a survey, one dedicated to data recording and another for mapping navigation (Figure 11), is recommended. PDAs should be protected in a waterproof case (or a sealable, transparent plastic bag) against water splash and potential rain. They should be powered by the external battery used for the spotlight. One battery (12 V 100 A) lasts 6-8 hours in continuous use under the load of one spotlight and two PDAs. All data are downloaded to a desktop computer for analysis at the end of a survey (see below).

Data analysis

Spotlight count data are usually collected and analysed to answer questions about changes in abundance and population size structure over time (Webb *et al.* 1984; Webb *et al.* 2000; Fukuda *et al.* 2011). Raw survey data can be imported into a GIS (Figure 15) and used for spatial analyses, such as mapping changes in crocodile distribution or assessing their dependency on habitat quality (e.g. Fukuda *et al.* 2007).

Relative density indices of abundance (the number of non-hatchling crocodiles sighted per kilometre of river surveyed) and biomass (kg of non-hatchling crocodiles sighted per kilometre of river surveyed) are typically calculated and compared to historical data (see example data in Tables 2–3 and Figures 16–17). Hatchlings (0.6 m or <2 ft) should not be included in these indices because of the high variance in both nesting abundance and hatchling success between years (Messel et al. 1981;

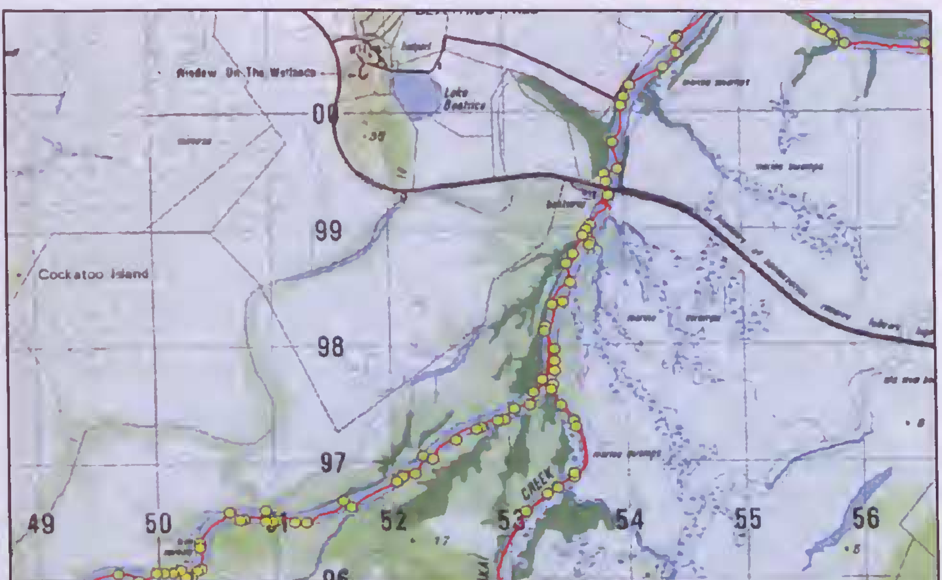


Figure 15. Example of crocodile spotlight survey locations (yellow dots) and the track of the survey run (red line) mapped in a GIS.

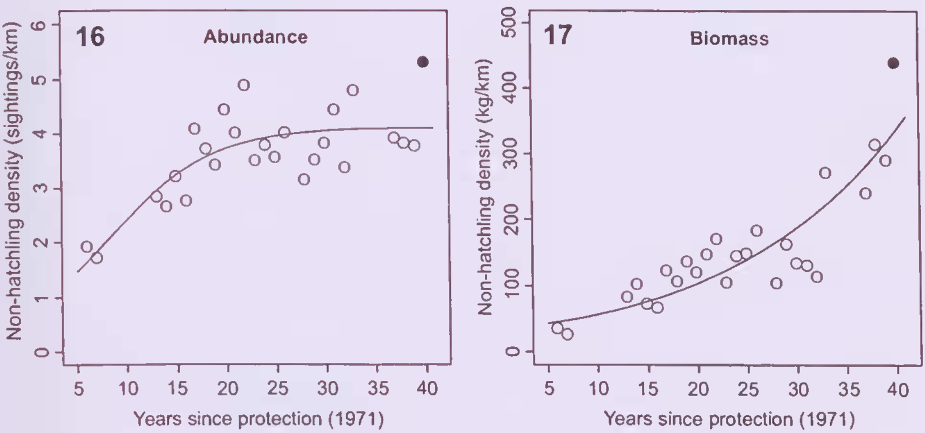
Fukuda *et al.* 2011). The distance of each survey should be measured on an accurate map, or by use of a GIS at an adequate scale (e.g. 1:50 000), along the midline of the river/stream rather than along the actual track taken by the boat. Estimating absolute abundance (e.g. crocodiles present in a river surveyed) from spotlight counts is often not practical because correction factors, even if derived from mark-recapture studies, are error prone and highly variable among rivers and years (Bayliss *et al.* 1986; Hutton & Woolhouse 1989).

Table 2. Example of survey data records from a river (140.74 km) in the NT, showing the number of crocodiles in each size class.

Crocodile size class (ft)	Example values for number of crocodiles	Crocodile size class (ft)	Example values for number of crocodiles
< 2	26	10-11	64
2-3	38	11-12	49
3-4	44	12-13	26
4-5	44	13-14	9
5-6	33	14-15	6
6-7	56	15-16	1
7-8	54	16-17	3
8-9	58	> 17	0
9-10	80	Eyes only	181

Table 3. Population abundance indices calculated from spotlight survey data (excluding hatchlings (< 2 ft) (Table 2). The calculation method for each size class, total number and biomass of crocodiles, and the relative density of crocodiles in abundance and biomass is provided in Webb and Messel (1978) and Fukuda *et al.* (2011). These indices are commonly compared to the historical data in graphs (e.g. Figures 16–17).

Population abundance indices	Example values
Total number of individuals	746
Density	5.30
Total biomass (kg)	61813.71
Biomass density	439.20



Figures 16–17. Examples of graphed crocodile density, present (closed symbol) compared with historical values (open symbols): **16.** Abundance; **17.** Biomass. The line is a fitted trend of the population change. The method for fitting a trend is described by Fukuda *et al.* (2011).

Discussion

The monitoring program for crocodiles in the tidal rivers of the NT has provided important information about the recovery of the wild population after protection (Messel *et al.* 1981; Fukuda *et al.* 2011). Data obtained were instrumental to the decision to transfer the Australian population of Saltwater Crocodiles from Appendix I to Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora' (CITES) (Webb *et al.* 1984). The survey program is an integral part of the safeguards and transparency built into the NT's formal management programs, approved separately at Territory and Commonwealth levels every five years (Leach *et al.* 2009; Delaney *et al.* 2010). Compliance with CITES requires ongoing demonstration that the export of skins is "not detrimental" to the survival of the species; the ongoing spotlight survey program meets this requirement and will be continued in order to monitor the sustainability of harvesting (Leach *et al.* 2009).

Various approaches have been attempted to minimise visibility biases and thus improve survey precision (Messel *et al.* 1981; Bayliss 1987; Choquenot & Webb 1987; Webb *et al.* 1989; Webb *et al.* 2000; Stiratt *et al.* 2001). Our description of the current monitoring program details an effective, successful, standardised survey method. We provide guidance on the logistics of these spotlight surveys, in the hope that this will improve monitoring efficiency and reproducibility.

The standardised monitoring procedures described and recommended here include resources that may not be readily available in other international contexts within which crocodile spotlight surveys are conducted, many of which are in developing countries. Thus the methodology may not be directly transferable and some aspects may need to be modified (e.g. using paper datasheets instead of a PDA for data recording). However, similar logistic constraints and visibility biases are likely to be encountered and may be addressed as described above. As shown in the NT and elsewhere, standardised spotlight surveying is a useful tool for monitoring wild crocodilian populations over the long term (Messel *et al.* 1981; Hutton & Woolhouse 1989; Webb *et al.* 2000; Fujisaki *et al.* 2011; Fukuda *et al.* 2011).

The status of crocodilians, and other wildlife, is essentially a relative measure that requires information on current abundance and/or distribution to be compared to historical or future reference points (Webb 1986). Historical data derived from standardised surveys provide the necessary stable baselines. Maintaining the current survey program, using the same methods, is clearly important for on-going management of crocodiles in the NT. If the program needs to be adapted in future, we would urge that any such adaptation is calibrated against the historical data to ensure that future survey results remain directly comparable with those collected historically.

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